4th Hardware Camp for Fast and Low-Light Detection

Son Cao (IFIRSE, ICISE)

MAR. 3RD 2025

This camp served as an invitation to particle physics research!

also to illustrate the interplay btw. particle and nuclear physics and *radiaton-based* technology

Interplay btw. science and technology

- **Transistor** was not invented by people who wanted to build computers but by physicists who dealing with counting the nuclear particles
- **Nuclear power** was not developed by one who seek for new power but Curies, Rutherford, and Fermi
- **Electron discovery** *(credited for by J.J. Thomson) was not for electronic industry but to understand the basics of atoms.*
- **Induction coils** *in motor cars and other vast application, not invented by who want to make motor transport but the principle of induction was discovered by M. Faraday*
- **Communication with electromagnetic waves,** *founded by H. Hertz who wanted to emphasized the beauty of physics*
- **Global positioning system (GPS)** *can't function well if not including the General Relativity*
- **Development of new materials and molecules** *benefits from precise mathematical techniques used in particle physics*
- **Word Wide Web** was *first invented by particle physicists to share information quickly and effectively around the world.*
- **Cancer therapy, drug development** *thanks to the particle accelerators*
- Behind of almost all photodetectors is **photoelectric effect,** which is discovered by Hertz in 1887 and modeled by Einstein in 1905
- Photodetectors developed and improved for particle physics *drive industrial application such as x-ray, medical scanning*
- Help for national security, *eg. cargo scanning, looking insides of the nuclear reactor*
- ...

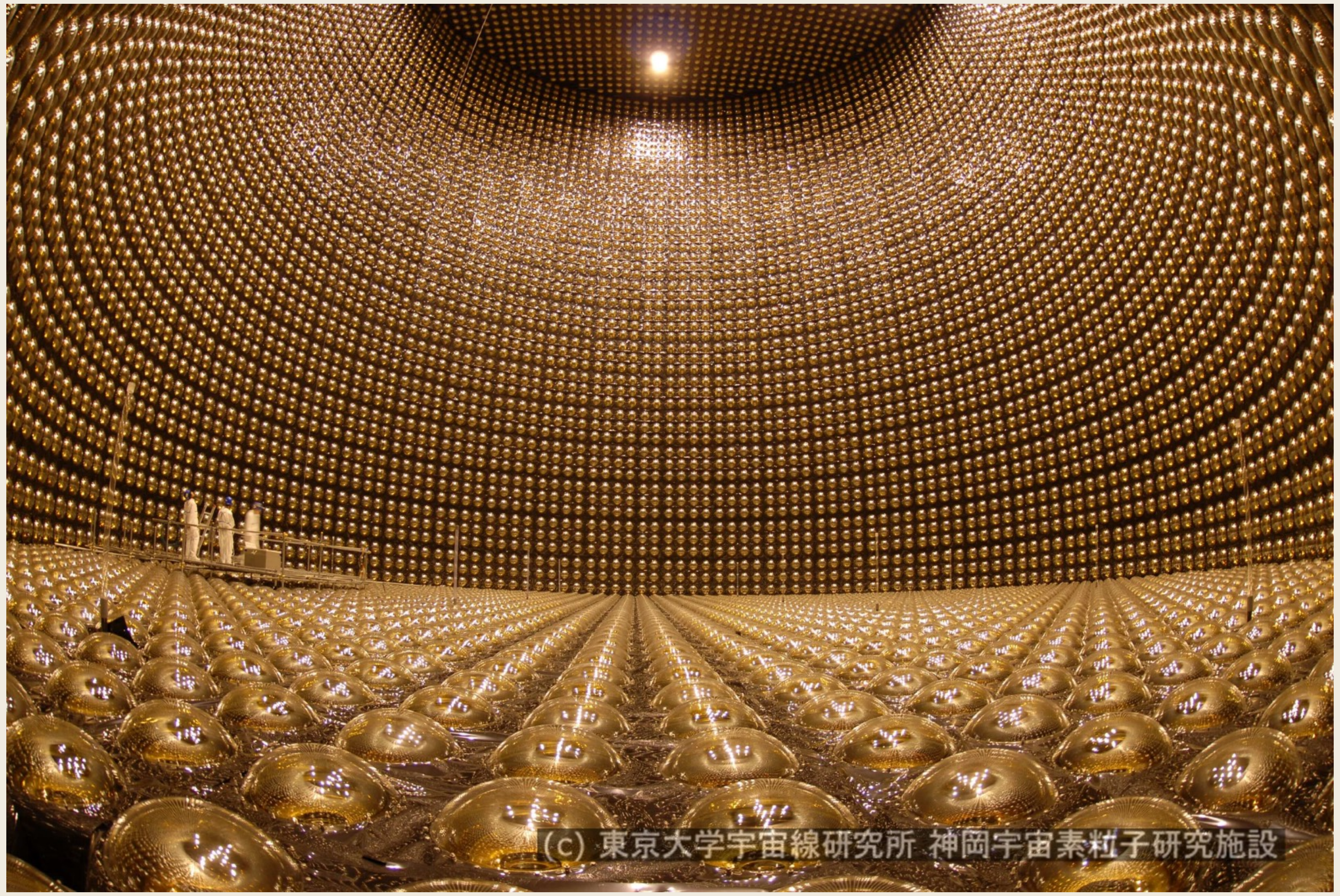
IN RESPONSE, ADVANCEMENTS IN TECHNOLOGY ARE CRITICAL FOR BASIC RESEARCH.

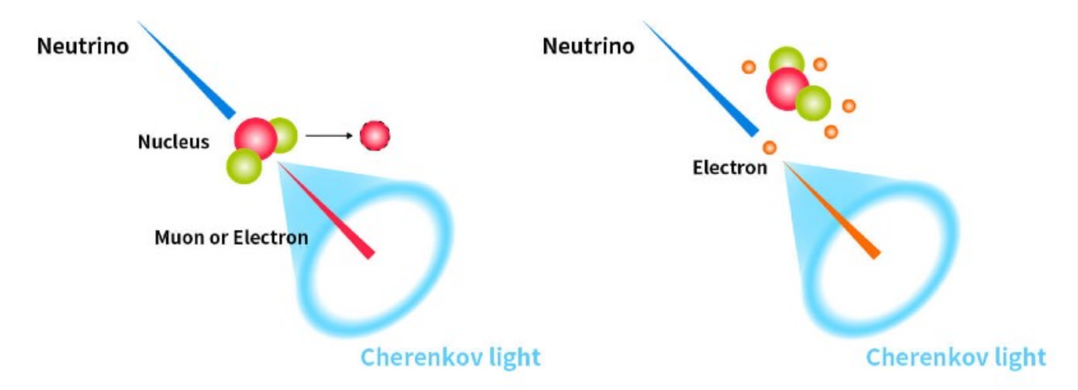
Particle physics, a key driver for innovation

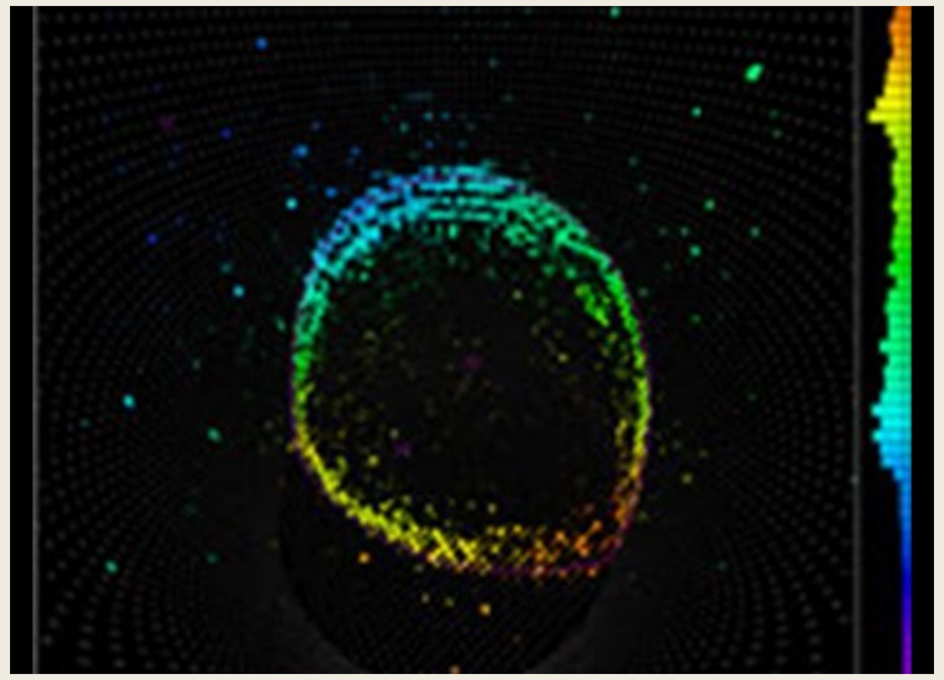
“The complex and sophisticated tools of particle physics are rich sources of new concepts, innovation and groundbreaking technologies, which benefit various applied research disciplines and eventually find their way into many applications that have a significant impact on the economy and society.”

https://cds.cern.ch/record/1431474/files/ParticlePhysicsEurope-New.pdf

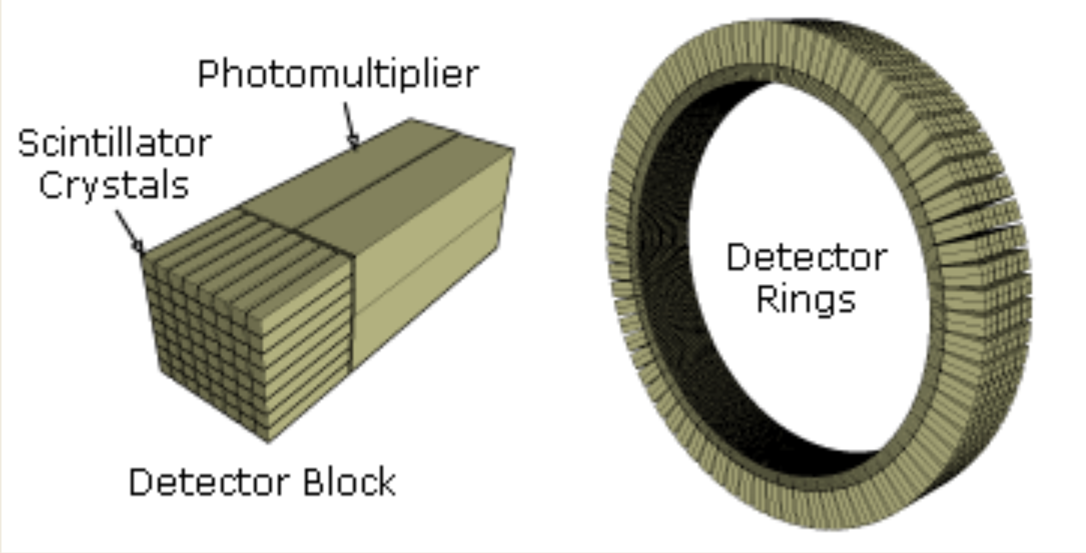
Interplay btw. physics and technology

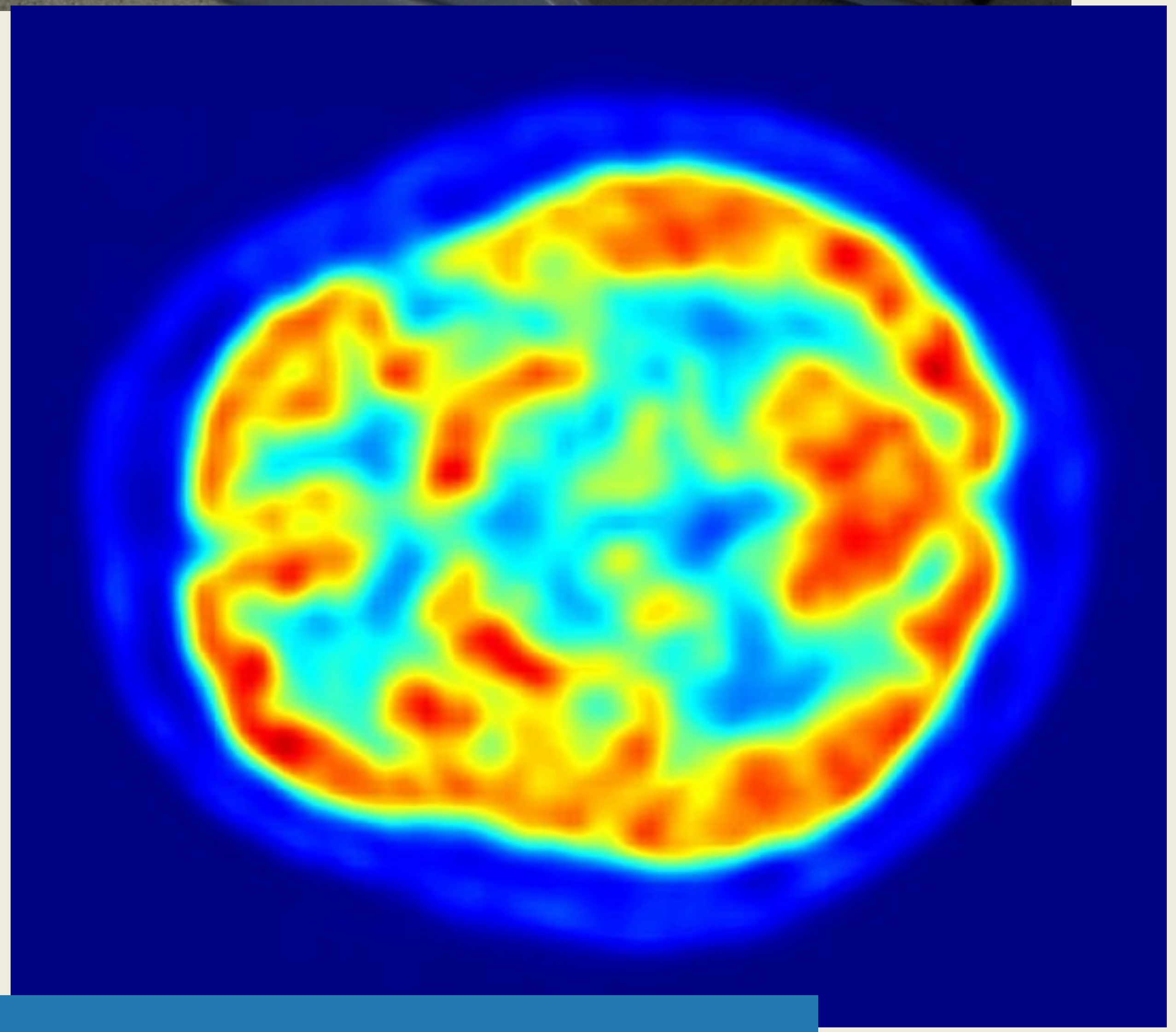






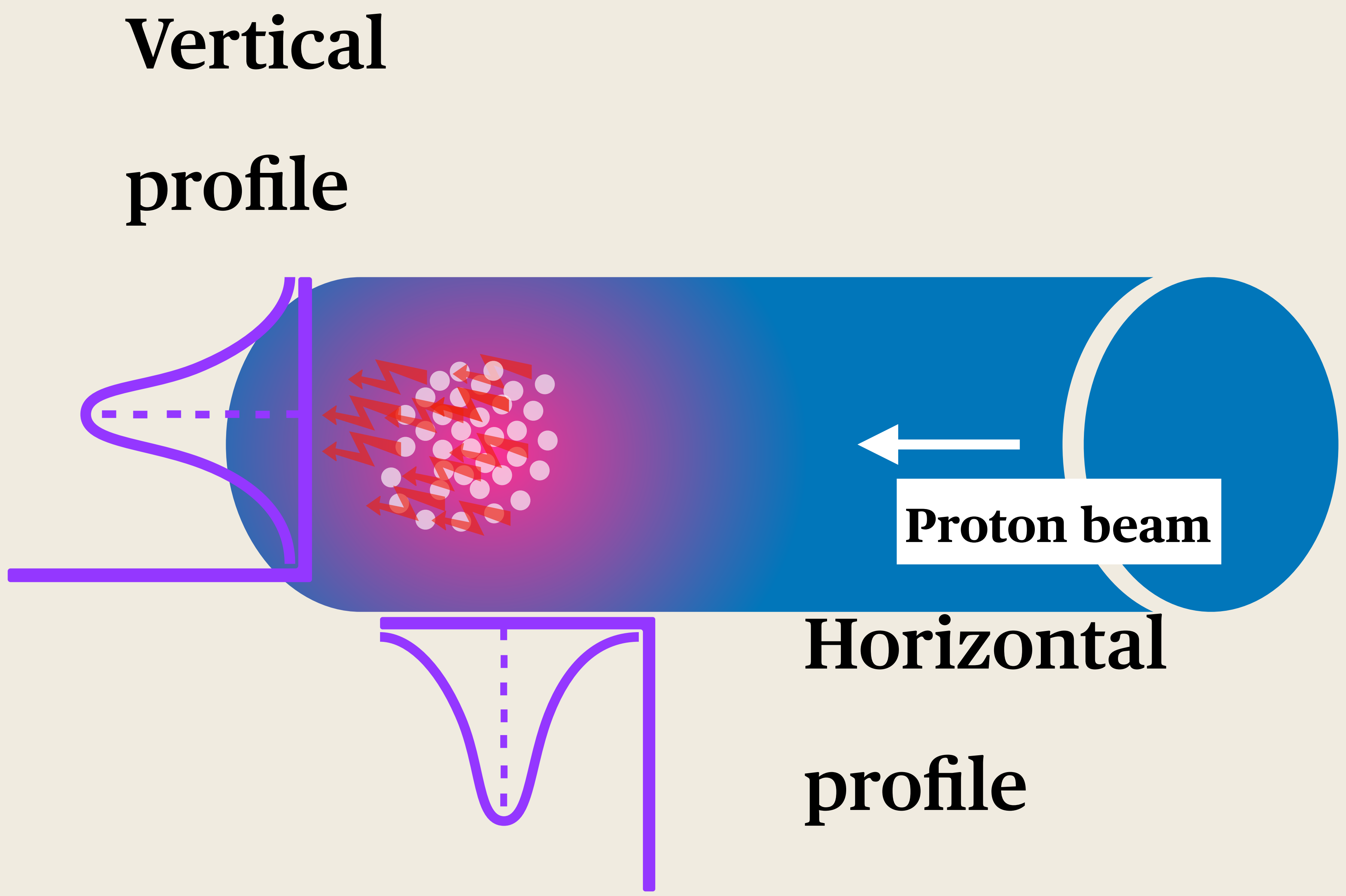
SUPER-KAMIOKANDE



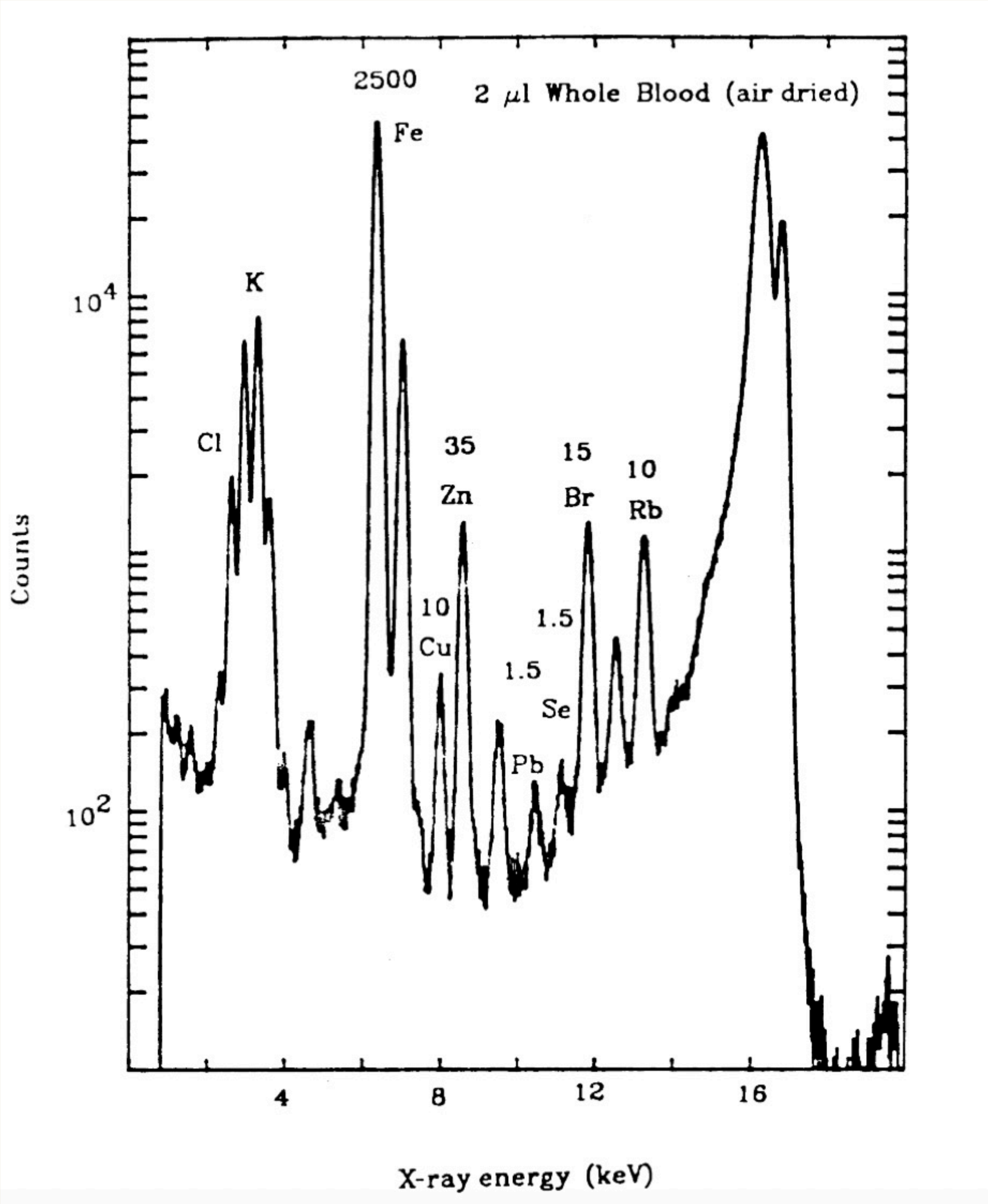


POSITRON EMISSION TOMOGRAPHY

Interplay btw. physics and technology



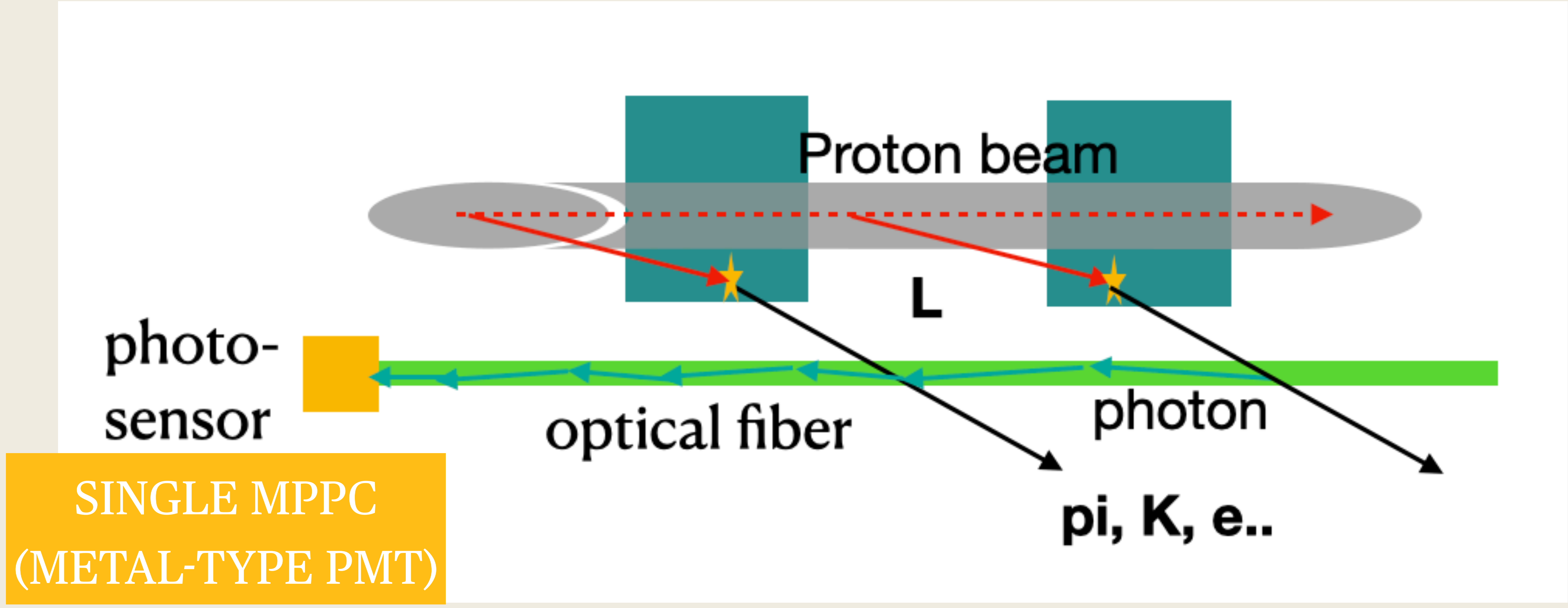
NON-DESTRUCTIVE BEAM-INDUCED FLUORESENCE MONITOR UNDER-DEVELOPING AT J-PARC NEUTRINO BEAMLINE

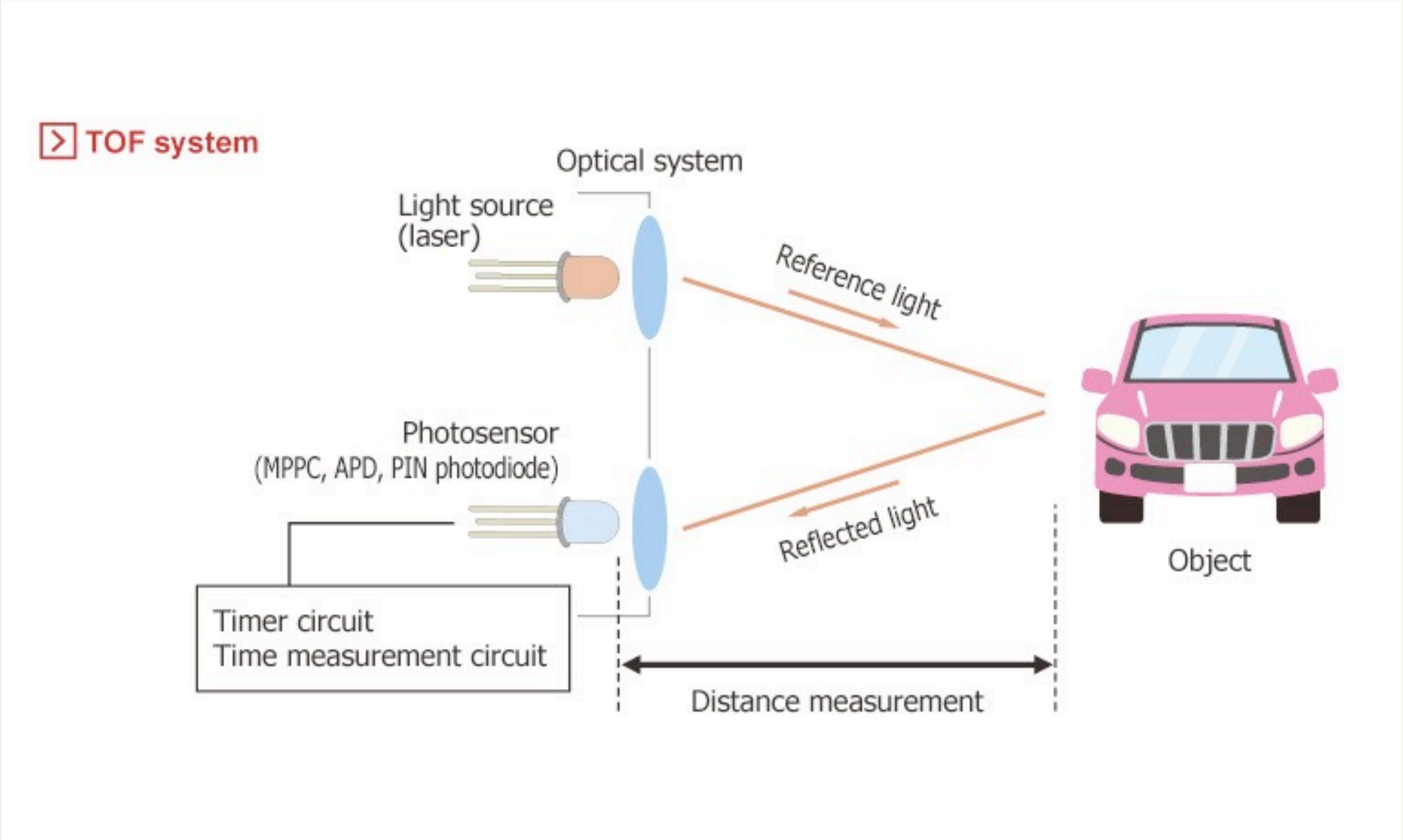


X-RAY FLUORESENCE OF HUMAN BLOOD

https://www-physics.lbl.gov/~spieler/USPAS-MSU_2012/pdf/I_Introduction.pdf

Interplay btw. physics and technology





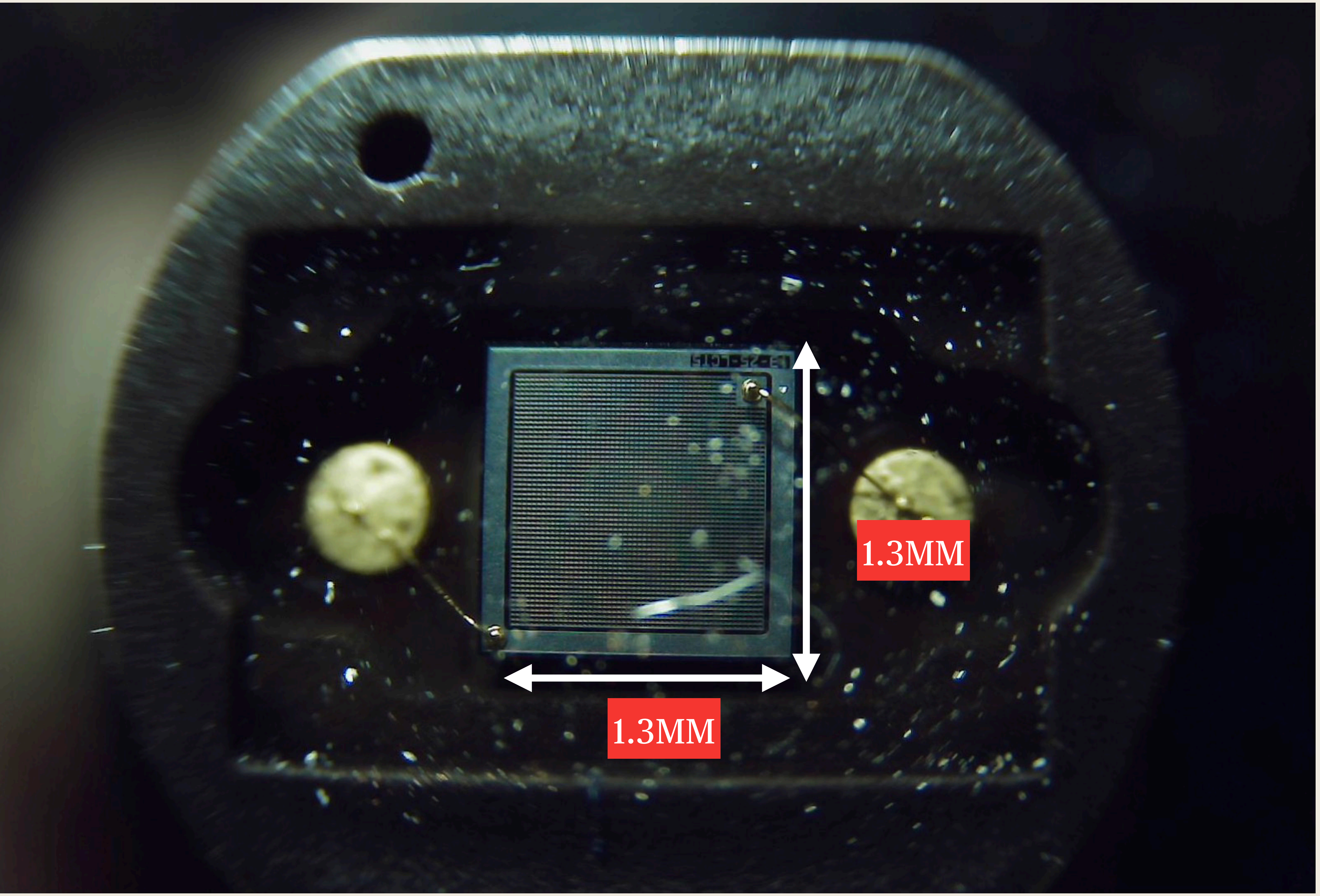
OPTICAL-FIBER BASED BEAM LOSS MONITOR UNDER-DEVELOPING AT J-PARC NEUTRINO BEAMLINE

CONCEPT OF LIGHT DETECTION AND RANGING (LIDAR) WITH TIME-OF-FLIGHT MEASUREMENT BTW REFERENCE LIGHT AND REFLECTED LIGHT —- HAMAMATSU PHOTONICS K.K

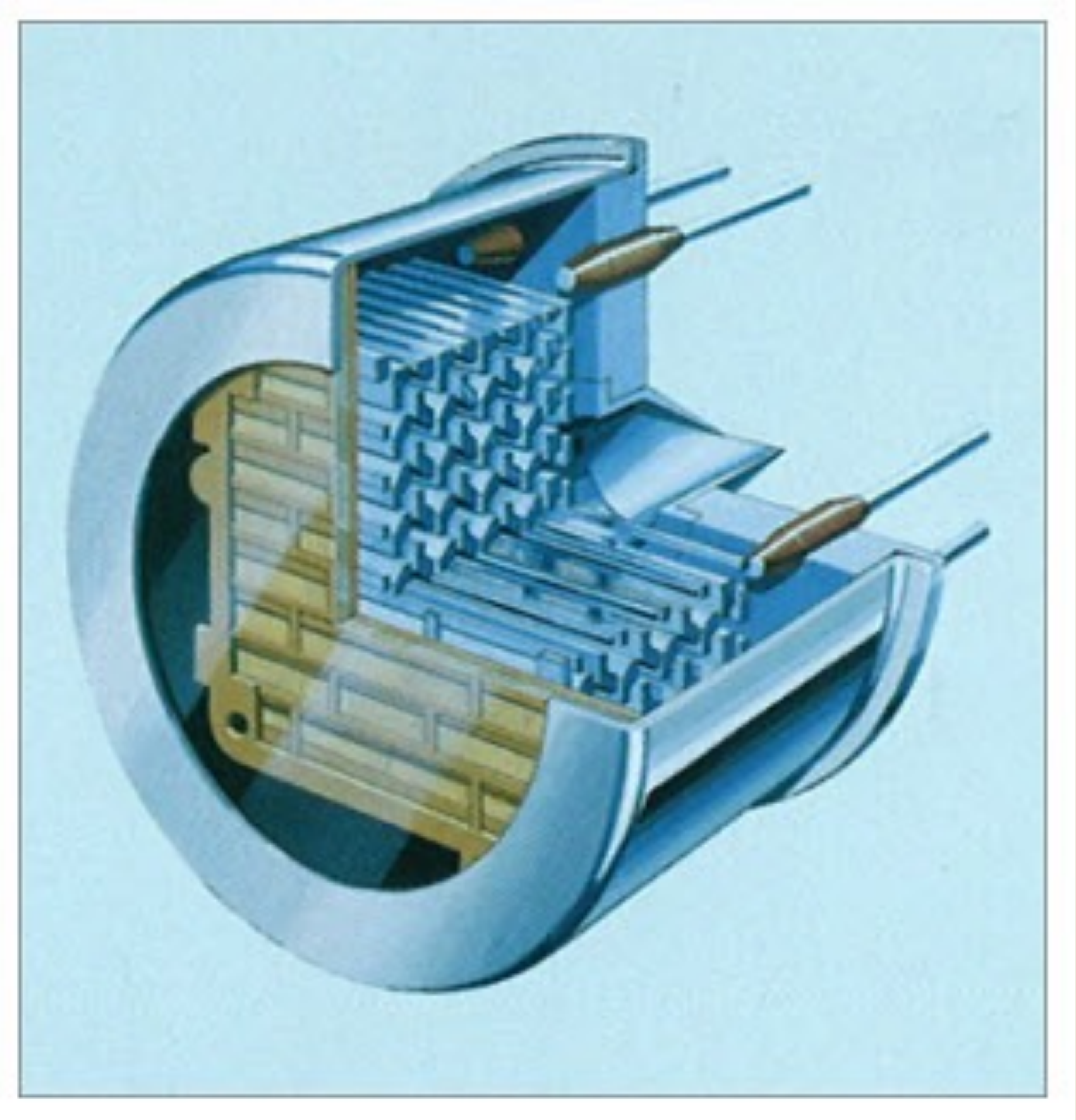
Why fast and low-light detection?

- Light is a *omnipotent* tools to *perceive* almost everything from the world of sub-atomic particles to the Cosmos
- Light is also a *sustainable and effective* solution for various sectors of modern life (*food, communication, entertainment, energy, environment, medicine…*)
- Modern life demands *high-speed* on almost everything ➜ Nothing (*physical object*) is faster than light (*in vaccum*). To harness power of light-speed, one may need help from fast-response (*ns-level*) photosensor.
  - *Do you know how fast can our eyes perceive?*
- When come to ns-level, you may not have an intense light (*photons*) reaching to your photosensor. You need technique to detect the faint light.

THE CAMP OBJECTIVE IS TO DEAL WITH FAST AND LOW-LIGHT DETECTION.
IT'S FUNDAMENTAL IN PARTICLE AND NUCLEAR PHYSICS, BUT CAN BE ADOPTED FOR MANY SECTORS IN OUR DAILY LIFE



A SI-BASED PHOTOMULTIPLIER, CALLED MPPC



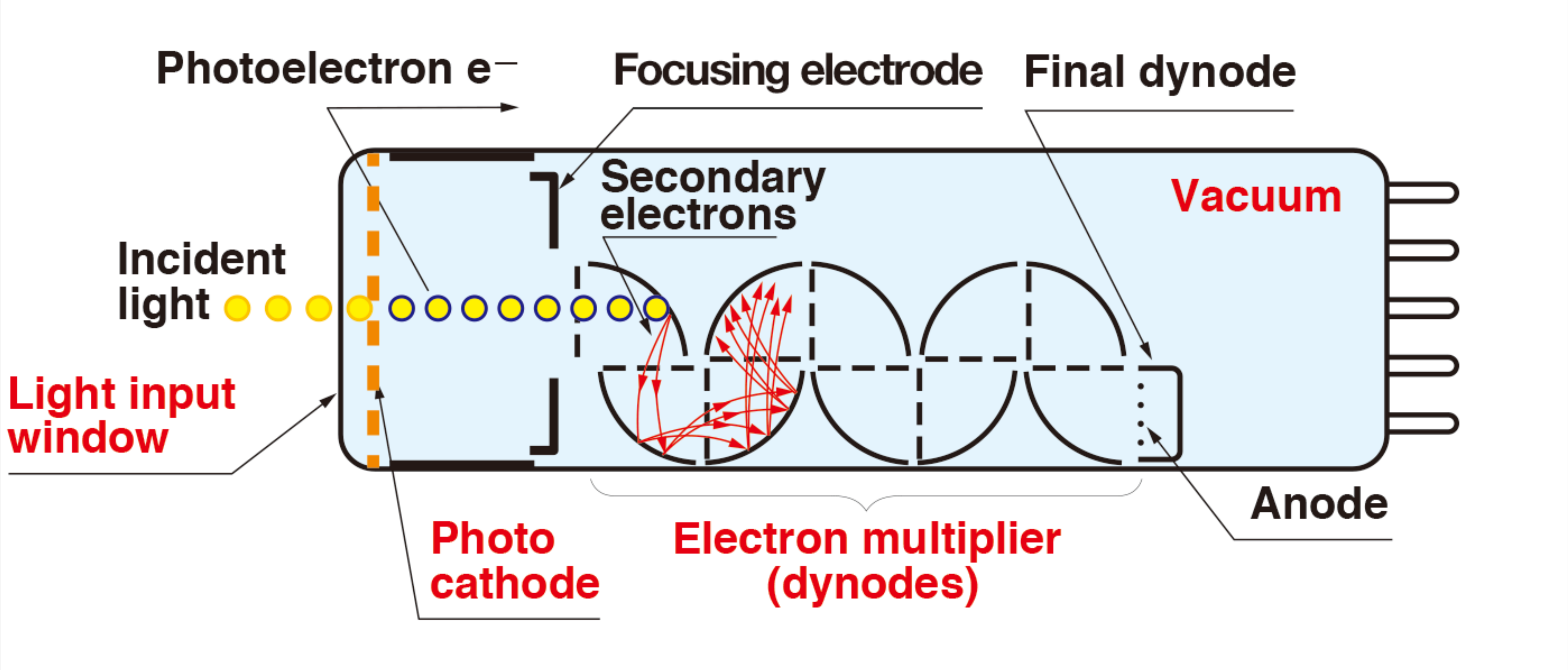
METAL PACKAGE PMT

These photosensor, we believe, are *capable and have a wide range of applications*.

We have experience to work with this device and would like to share w/ you!

Ref. “Introduction to photodetectors”

A glance at PMT



20-inch diameter PMT for research by Hamamatsu

Facility name	Kamiokande (From 1983 to 1996)	SuperKamiokande (From 1996 to present)	HyperKamiokande (In planning stage)
Type No.	R1449	R3600	R12860
Collection efficiency	40 % to 50 %	70 %	90 %
Electron transit time spread	4.4 ns	2.2 ns	1.0 ns

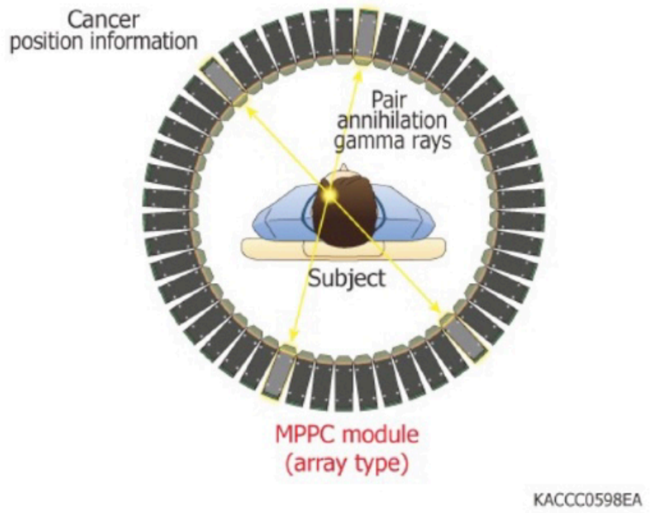
https://www.hamamatsu.com/jp/en/product/optical-sensors/pmt/applications.html

Key features of MPPC and application

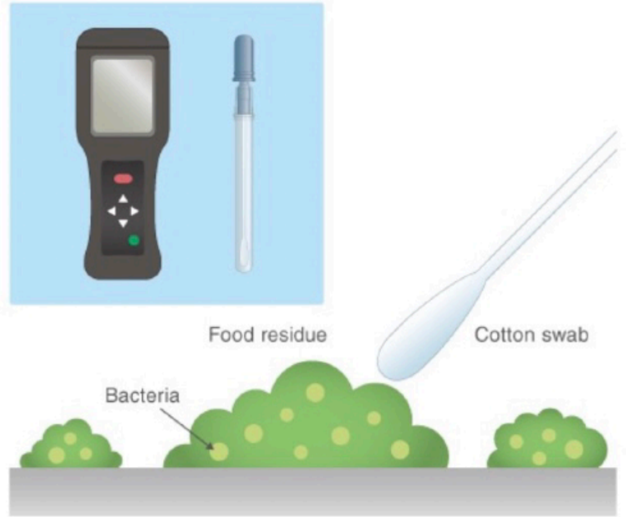
- High electrical gain: 10^5 to 10^6
- Single photon-resolving capability with relatively high dynamic range (*few p.e. to ~ 10k p.e*)
- Excellent time resolution and quantum detection efficiency
- Compact and portability
- Immune to the magnetic field (*vs. PMT usually need magnetic shield*)
- Low operation voltage (*~50-70V DC vs. 1000V of PMT*); simple readout circuit, high integrated capability
- Relatively cost-effective

Distance Measurement (LiDAR)

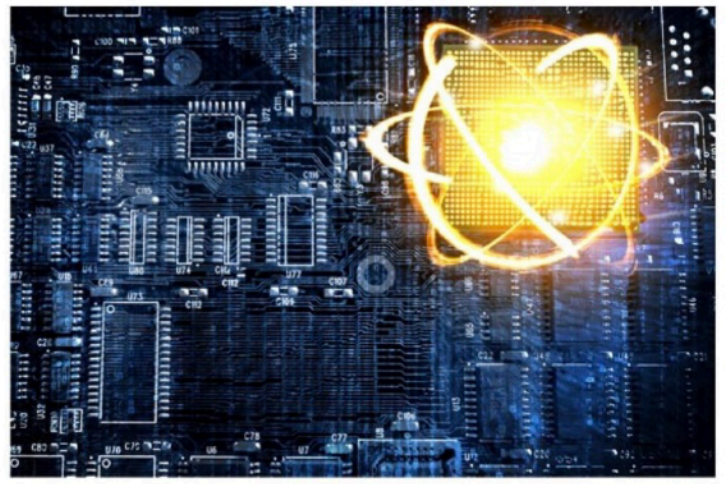
PET (Positron Emission Tomography)



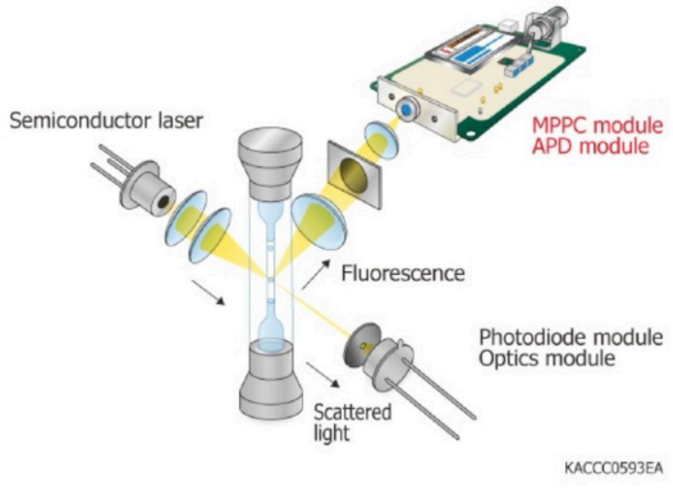
Hygiene Monitor



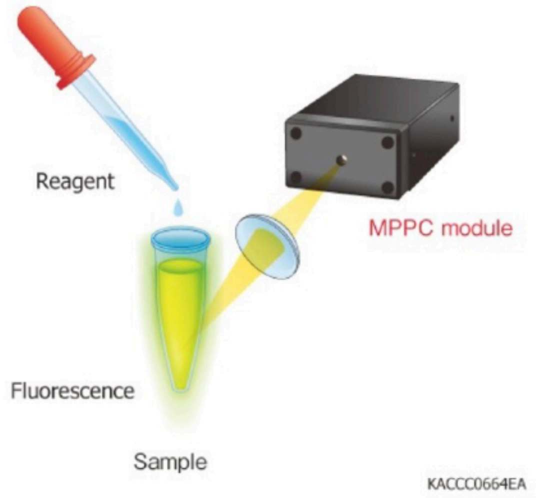
Quantum Computing & Cryptography



Flow cytometry



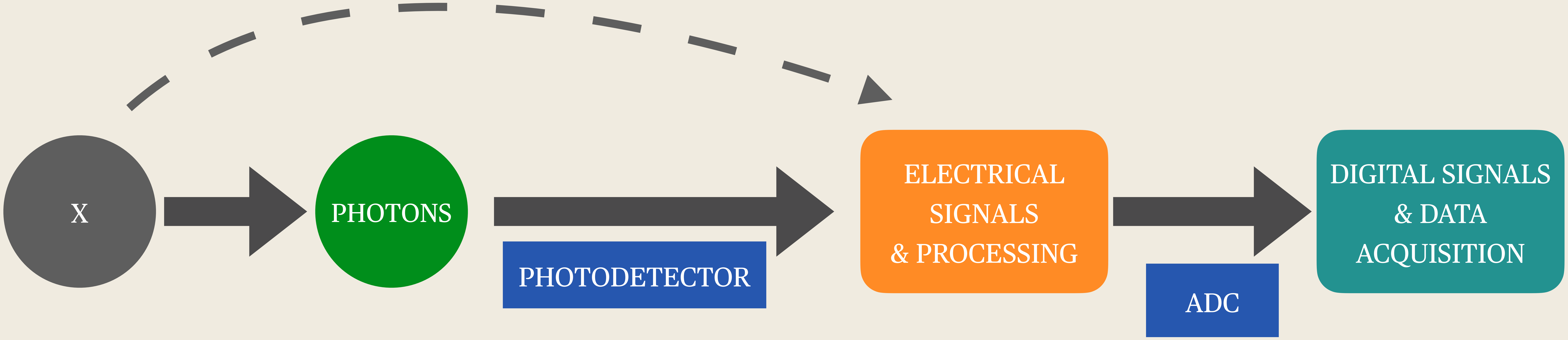
Fluorescence & chemiluminescence measurement



https://www.hamamatsu.com/jp/en/product/optical-sensors/mppc/application.html

Role of photodetectors

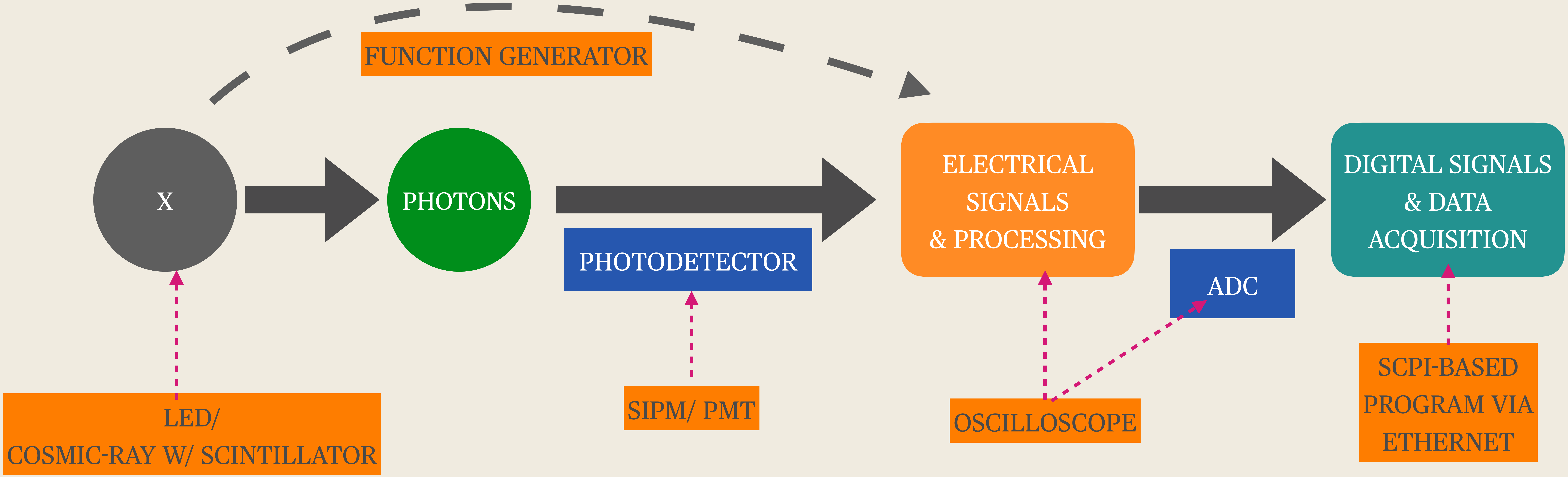
Typically, we sense/measure the things (*elementary particles, chemical elements…*) by converting them into the optical signals, which can subsequently be detected by the photodetectors



Signal processing and data acquisition are needed to obtain information from photosensor

Role of photodetectors

Typically, we sense/measure the things (*elementary particles, chemical elements…*) by converting them into the optical signals, which can subsequently be detected by the photodetectors



Most of Vietnamese students are lacking in hardware

(PARTICULARLY TRUE IN PARTICLE AND NUCLEAR PHYSICS)

- Did you use multimeter before?
- Did you use oscilloscope before?
- Did you use function generator before?
- Did you use DC power supply before?
- Did you use NIM modules before?
- …

THE CAMP IS ALSO TO PROVIDE SOME SKILLS WITH THESE PARTICULAR HARDWARES

Most challenging for fast and low-light detection?

- Make use of the *fast-response* photosensors
- Suppress the noise, light lightening/shielding
- Utilize the fast signal processing
- ....

WE WILL GO (PARTIALLY) THROUGH THESE CHALLENGING

Before and during the 2003 Northeast blackout, a massive power outage that affected 55 million people. Photo by of Todd Carlson

Mon, 3

- 7:30am Bus from hotel to ICISE
- 8am Welcome address by ICISE
- 8:15am Welcome address by Prof. Oyama (Prof. Yuichi Oyama (KEK))
- 8:45am Logistics/safety (Son Cao
- 9am Short break
- 9:15am Students' self-intro
- 10:30am Elementary particle and photons (Hong Van (IOP, VAST))
- 12pm Lunch break
- 1:30pm Introduction to photodetectors (Son Cao (IFIRSE))
- 2:30pm Short break
- 2:45pm SiPM/PMT Hands-on Act #1

Tue, 4

- 7:30am Bus from hotel to ICISE
- 8am Introduction to basic electronics/ Simulation (Son Cao & Sang Truong (IFIRSE))
- 9:15am Short break
- 9:30am Introduction to cosmic ray (Atsumu Suzuki (Kobe Univ.))
- 10am Cosmic ray muon and muon radiography (Yuichi Oyama (KEK))
- 10:30am Electronics for cosmic ray muon detection (Yuichi Oyama (KEK))
- 11:30am Guidance for presentation (Yuichi Oyama, KEK)
- 12pm Lunch break
- 1:30pm SiPM/PMT Hands-on Act #2
- 4pm Short break
- 4:15pm Photon detection from Quantum view (Chau Nguyen (Univ. of Siegen))

Wed, 5

- 7:30am Bus from hotel to ICISE
- 8am PET as MPPC application, (Dr. John Paul Cesar, The Univ. of Texas at Austin)
- 9am Short break
- 9:15am GEANT4 introduction and tutorial (Nam Tran (Boston Univ.))
- 11:15am Tracking and calorimetry detectors ((Son Cao, IFIRSE))
- 12pm Lunch break
- 1:30pm FPGA tutorials (1) (Michael Holik (Czech Tech. Univ.))
- 3pm Short break
- 3:15pm SiPM/PMT Hands-on Act. #3

Thu, 6

- 7:30am Bus from hotel to ICISE
- 8am Super-Kamiokande Triggering System (Guillaume Pronost (ICRR, Univ. of Tokyo))
- 9am Short break
- 9:15am FPGA and tutorial (2) (Michael Holik (Czech Technicak Univ.))
- 12pm Lunch break
- 1:30pm FPGA tutorials (3) (Michael Holik (Czech Tech. Univ.))
- 3pm Short break
- 3:15pm SiPM/PMT Hands-on Act. #4

Fri, 7

- 7:30am Bus from hotel to ICISE
- 8am Fast machine learning (Nhan Tran (Fermilab))
- 9am Timepix introduction (Michael Holik (Czech Technicak Univ.))
- 10am Short break
- 10:15am SiPM/PMT Hands-on Act #5
- 12pm Lunch break
- 1:30pm Fast machine learning: tutorial (Duc Hoang (MIT/CERN))
- 3pm Short break
- 3:15pm SiPM/PMT Hands-on Act. #6

Sat, 8

- 7:30am Bus from hotel to ICISE
- 8am Timepix demonstration (Michael Holik (Czech Technicak Univ.))
- 10am Short break
- 10:15am Group's report preparation
- 12pm Lunch break
- 1pm Student groups' presentation
- 2:30pm Conclusion

THE CAMP PROGRAM IS DESIGNED TO PROVIDE HANDS-ON ACTIVITIES WHILE ALSO PROVIDING BACKGROUND, RELEVANT KNOWLEDGE FROM SHORT LECTURERS.

We called “camp” for some reasons

- We’re learning and exploring together. There are somethings we don’t know yet.
- Our main approach: students learn from his/her hands-on experiences
- The camp is for students to learn actively, not for us to teach passively. So try to get most of it. Don’t be shy. If you don’t ask, we can’t know if you understand or not.

THE CAMP LIKES AN “INFORMAL” FORUM

SAFETY FIRST!!!

- Lab safety rules are posted on the door. Please take a look.
- Electric equipments: (AC 220V vs. 110V; AC vs. DC power). Think at least twice before plug in/out; turn on/off.
- Do not take out or put in any item without permission
- *Swimming/ Not good season yet*

Many things in the lab and the best approach to manage is to
(1) *put at right place*
(2) *clean and return after use*

Please,

NO FOOD inside,

DRINK at designated areas,

CLEAN after using,

MINDFUL of the others.

DON'T turn off any PC in lab

Indoor Slipper only NO 🦶 BARE foot

WE TRIED OUR BEST TO MAKE PROPER GROUNDING. BUT PLEASE USE SLIPPER TO AVOID THE ELECTROSTATIC SHOCK

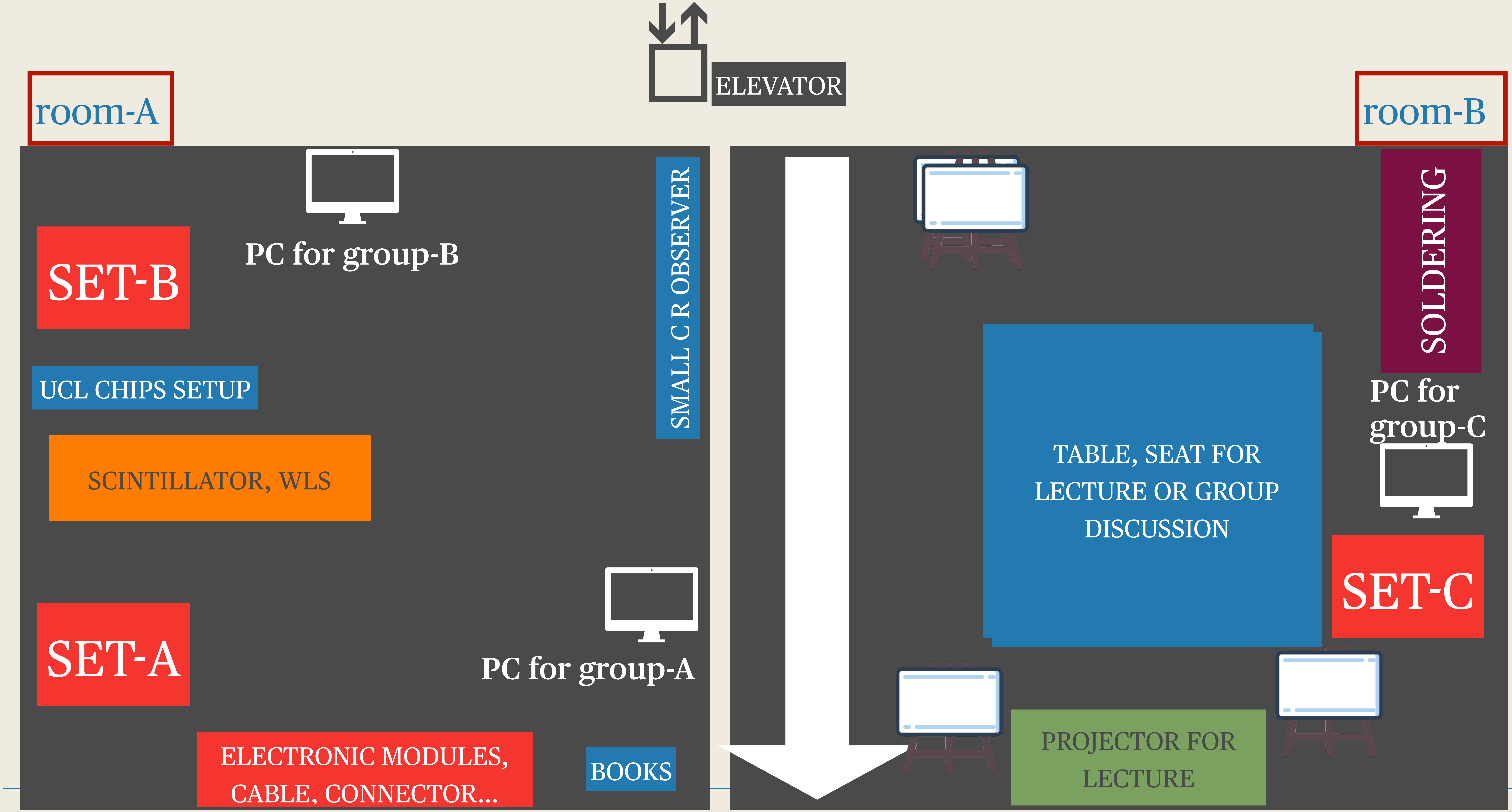
Three main study objectives for SiPM/PMT hands-on

1. Explore the properties of photodetectors (dark count rate, electric gain or size of a single photoelectron, rising/falling time…)
2. Measure the time-of-light of photon in the optical fibers (group-A); light profile (group-B); and light spectrum (group-C)
3. Muon counter, the rate (angular dependence); observing muon decays if having time

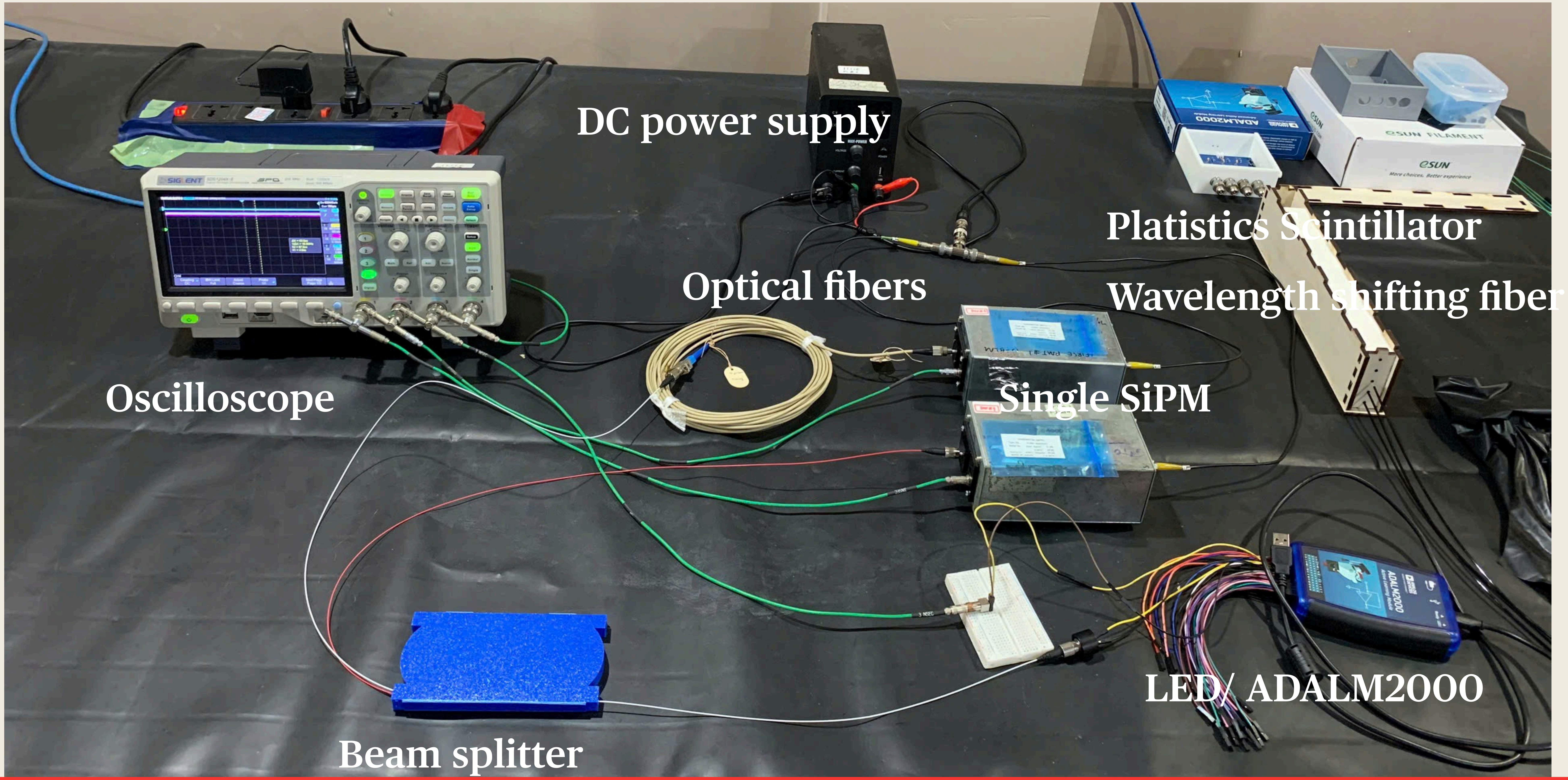
DETAILS WILL BE EXPLAINED DURING THE HANDS-ON ACTIVITIES

- We will have final presentation for each group on Saturday, Mar. 8
- We ask for final science report for each group by Mar. 22nd (2 weeks after the camp) ⬅ take note carefully during the camp

Room map for hardware camp 3/3-9/3



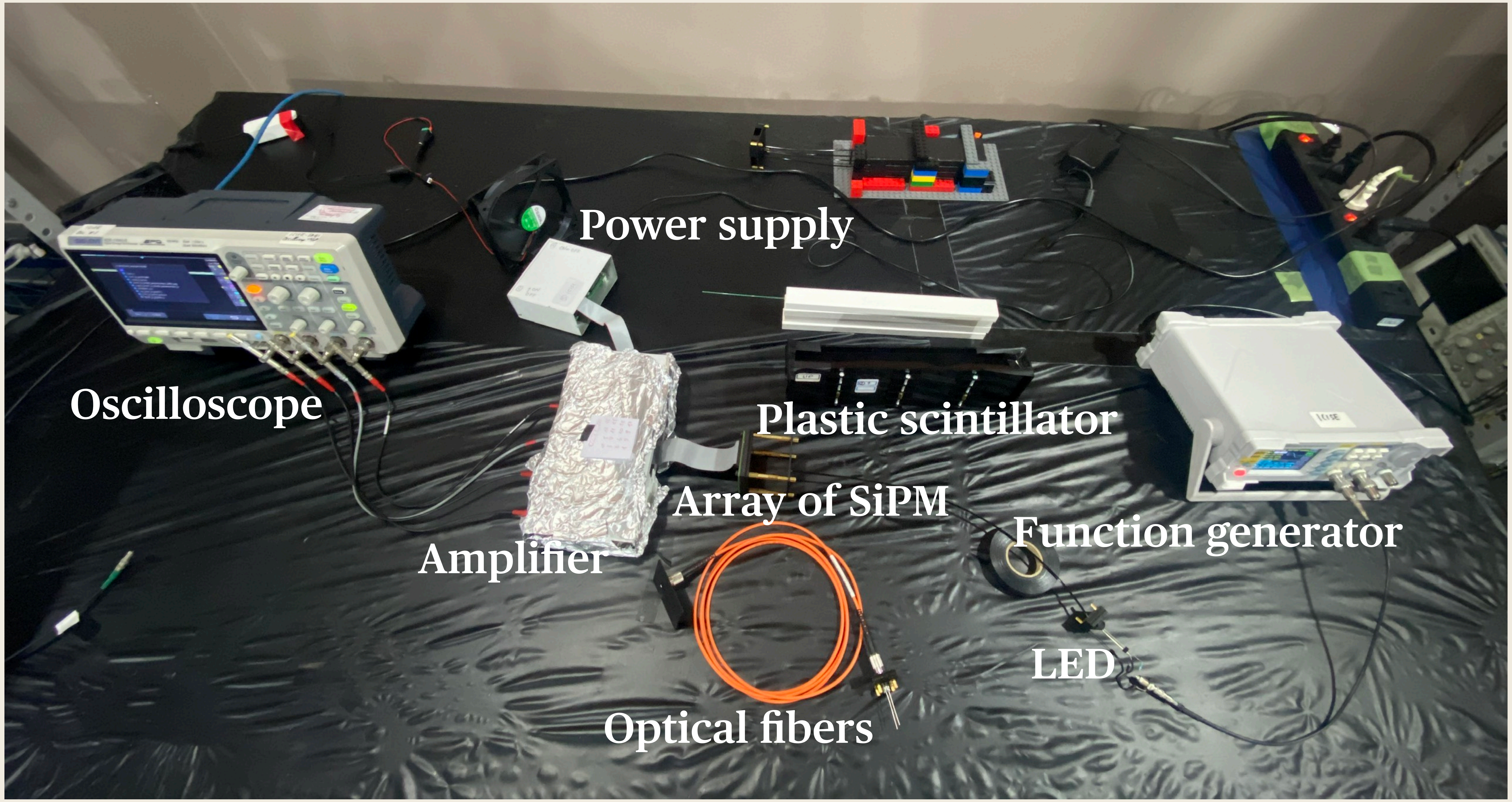
For Team-A



DETAILS WILL BE EXPLAINED DURING THE HANDS-ON ACTIVITIES

- Members: TBD
- Mentors: M.Sc. Sang Truong

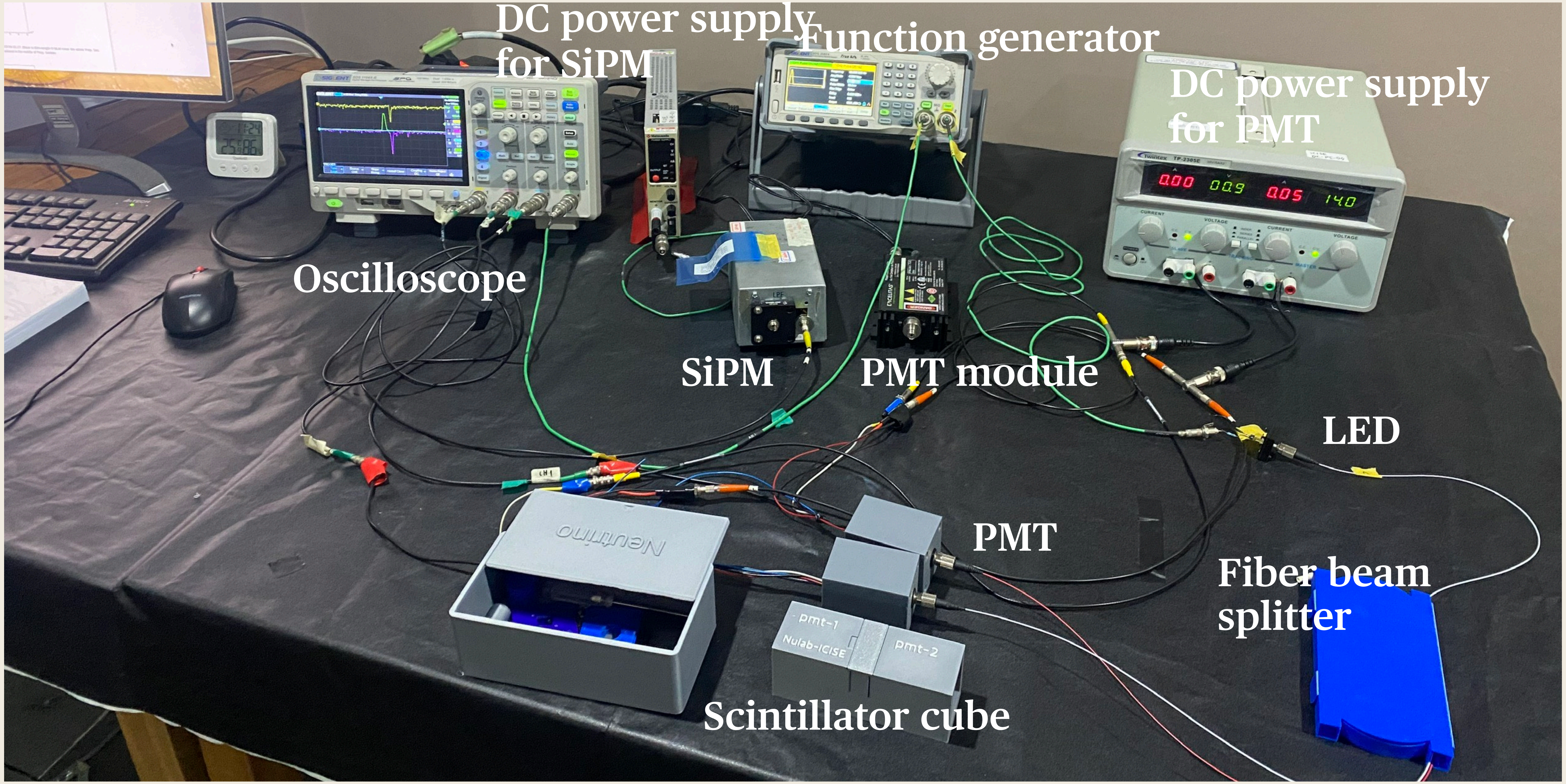
For Team-B



DETAILS WILL BE EXPLAINED DURING THE HANDS-ON ACTIVITIES

- Members: TBD
- Mentors: Ph.D student Quyen Phan

For Team-C



DETAILS WILL BE EXPLAINED DURING THE HANDS-ON ACTIVITIES

- Members: TBD
- Mentor: Dr. Son Cao

Soldering station

Use protective glass!

Do not adjust the soldering temperature without discussion.

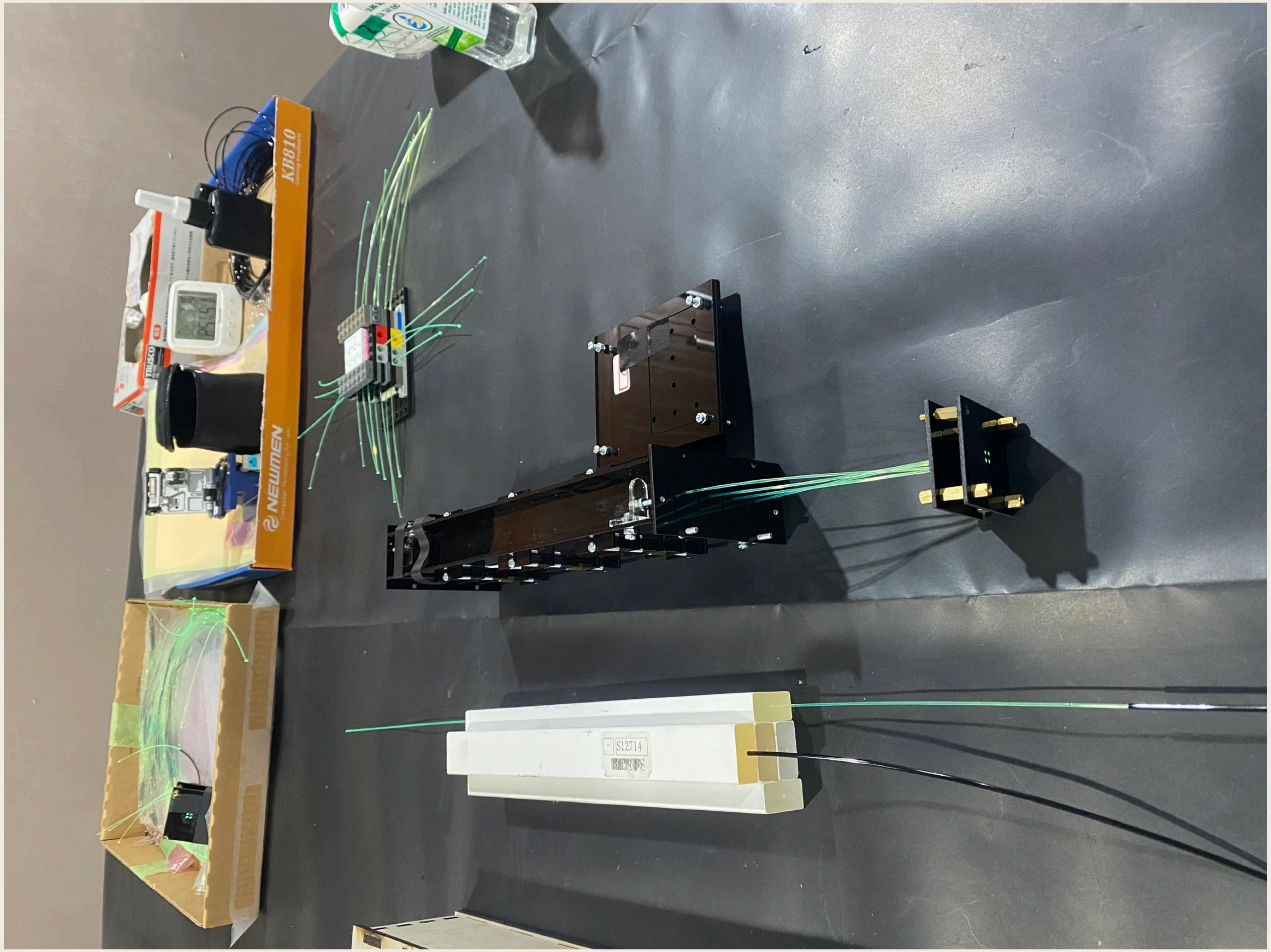
Do not hold metal part which contacts with the soldering tip.

Scintillators, wavelength shifting fibers for student to fabricate and assembly

Be gentle!

Do not bend the fiber too much.

Do not shine UV light directly on your skin, your eyes



Books and some technical note

If you want to take out, please put your name and remember to return

KEK

KYOTO UNIVERSITY

YOKOHAMA National University

We greatly thank for your donation

WITHOUT THEIR GENEROSITY, THIS INITIATIVE IS IMPOSSIBLE.

Brief introduction of Neutrino Group, IFIRSE

HTTP://IFIRSE.ICISE.VN/NUGROUP/

A science and education urban area is emerging

Neutrino group formed 2017

Core group members of Japan side

- **T.Nakaya (Kyoto Univ.): scientific group leader**
- Atsumu Suzuki (Kobe Univ.)
- Yuichi Oyama (KEK)
- Makoto Miura (Kamioka, ICRR, Tokyo)

International Advisory Committee

- M. Nakahata (Kamioka, ICRR, Tokyo, JP)
- T. Kobayashi (KEK, JP)
- Karol Lang (The Univ. of Texas at Austin, USA)
- Jacques Dumarchez (LPNHE- Univ. of Paris, FR)

MOU signing ceremony in July 2017

https://ifirse.icise.vn/nugroup/About-us.html

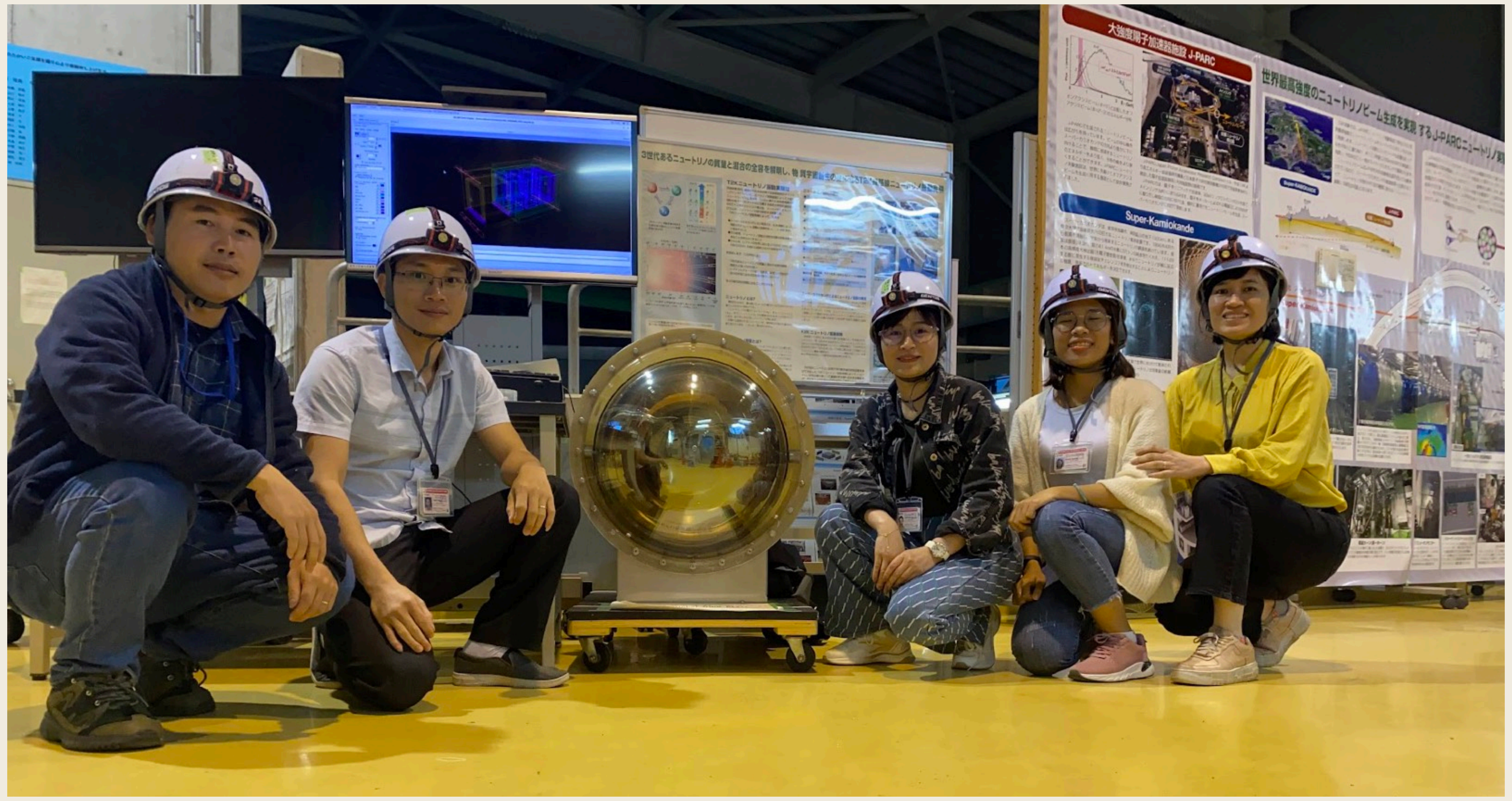
NEUTRINO is our 💟

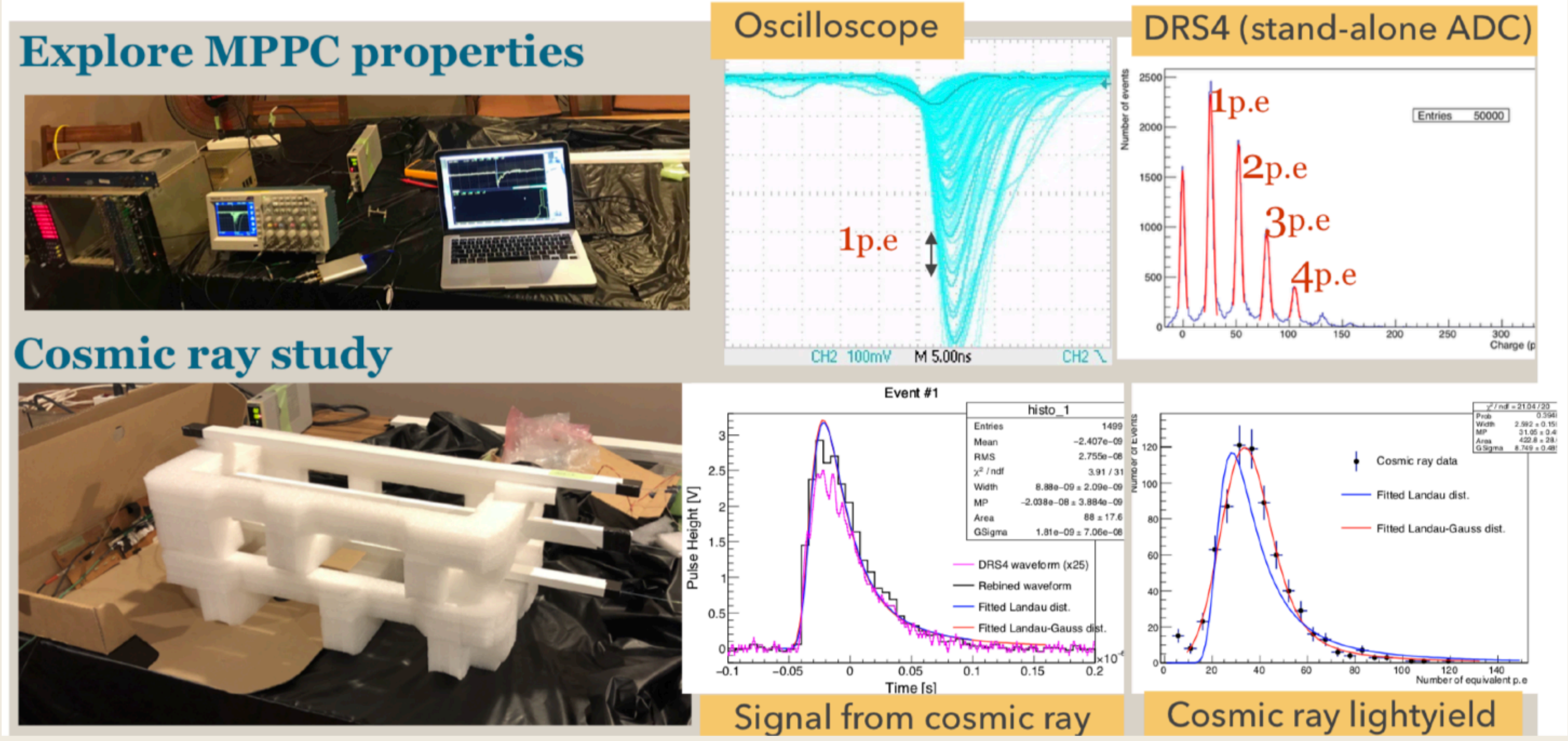
If you are interested in Neutrino, come and talk with us during the break times.

What are we doing?

<u>Work as an international collaboration</u>

- **T2K** (Oc. 2017~) an international accelerator-based long-baseline neutrino experiment in Japan (~500 collaborators from 65 institutes of 12 countries)
  - Neutrino Event Generator, Neutrino Oscillation Analysis
- **WAGASCI** (now part of T2K) (Feb. 2018~) a neutrino-nuclei interaction-focused experiment in Japan,
  - **Detector construction (our students are working directly with Japanese and other colleague)**
- **Super-Kamiokande** (Jun. 2021~) to search for the diffuse supernova neutrinos and proton decay





<u>Build the lab at ICISE:</u>

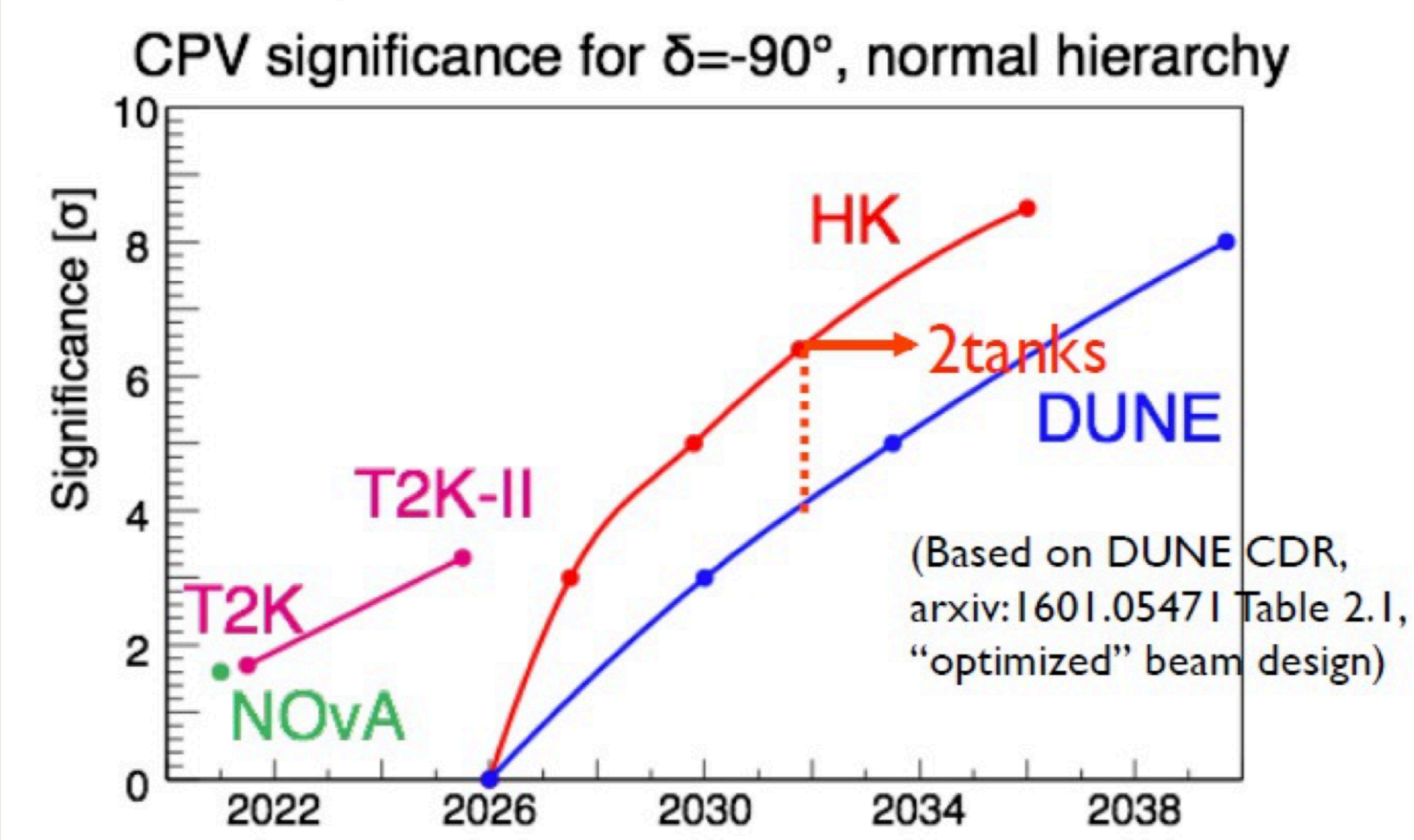
- Advance the single-photon sensitive sensor with the the plastic scintillators
- Detector prototypes for the cosmic ray measurements and other applications

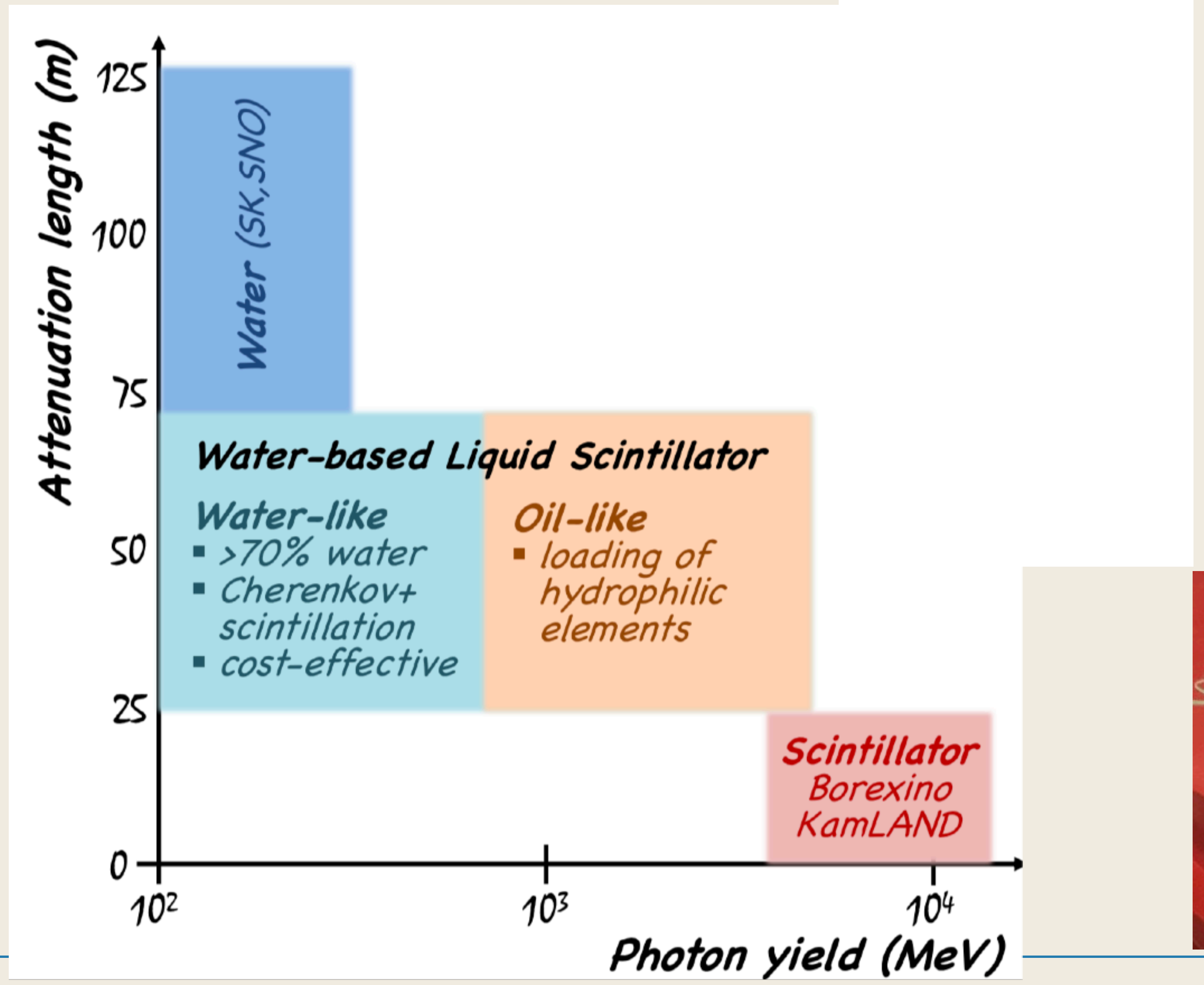
- Organize annually *Vietnam School on Neutrinos (2024 will be the 8th in the series)* and *Hardware camp (2024 will be 3rd in the series)*to **train and encourage students and young researchers working on neutrino physics**
- Host the *International Symposium on Neutrino Frontiers (2018)*
- Host *Neutrino Workshop at IFIRSE (2023); and will be Neutrino Conference (2025)*

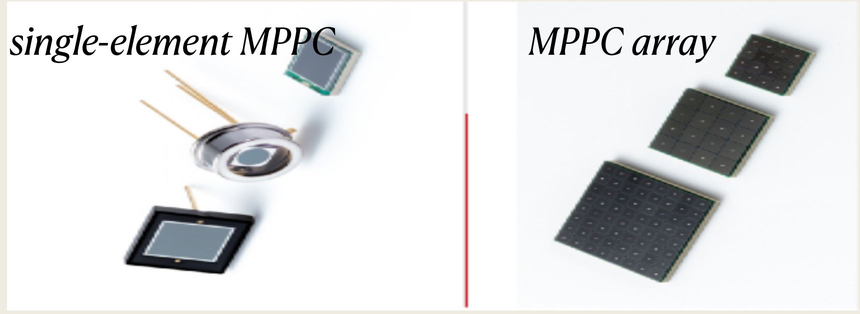
The path forward

International collaboration work

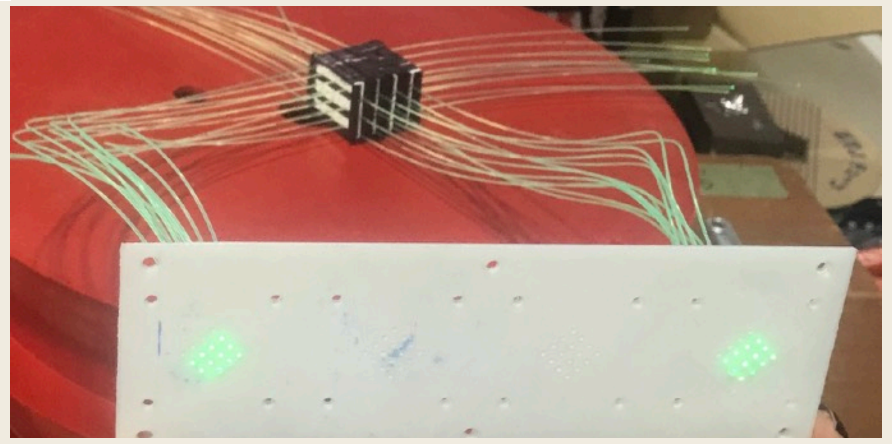
- **Keep working with T2K and Super-K experiment**
  - CP violation, neutrino mass ordering, and other unknown via the neutrino oscillation measurements
  - Search for diffuse supernova neutrinos and proton decay
- **Aim to join Hyper-Kamiokande experiment in the near future**
  - Effectively 8 times larger than Super-Kamiokande, will start operation from 2027
  - Along with data analysis, we may want to work on PMT







Portraits of MPPCs (taken from Hamamatsu)



Lab development

- Photosensor, eg. Multi-pixel Photon Counter, (micro)PMT
- Scintillator materials, eg. Water-based Liquid scintillator
- Lab test bench, detector prototype


icise
QUY NHON
VIETNAM
Please consider apply ICISE internship
https://ifirse.icise.vn/nugroup/internship/index.html

Enjoy the camp!

Let try this after hard-work!!!